



Landcare Research
Manaaki Whenua

Soil Horizons

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Special issue: SOIL CARBON



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Editorial

This issue of Soil Horizons reports on our soil carbon (C) research addressing the need to enhance the terrestrial C pool and reduce carbon dioxide (CO₂) emissions to the atmosphere.

Soil C provides the framework for soil organic matter, the life support system of the soil, and makes up about half of its composition. Globally the top metre of soil contains more C (about 1500 Gt (billion tons), than the combined C in the terrestrial vegetation (≈ 600 Gt) and atmosphere (≈ 750 Gt).

Some cultivated soils have lost up to two-thirds of their original soil organic matter (SOM), and this depletion is accentuated by intensive land use for global food supply.

When soils no longer accumulate C, because of cultivation, erosion or drought, existing reserves continue to be lost by leaching as dissolved organic C, and by oxidation to the atmosphere as CO₂. During the period 1850–2000, global emissions of CO₂ resulting from land-use change and soil cultivation, are estimated to be about half of that due to fossil fuel combustion.

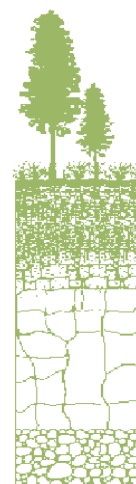
Restorative management of agricultural soils not only reduces the rate of enrichment of atmospheric CO₂ but also has positive impacts on food security, agro-industries, water quality, and the environment.

Researchers in Landcare Research, in New Zealand and globally are focussing on the assessment of soil C stocks and mitigation strategies to slow down, halt or even reverse loss of organic C from soils.

In this issue of Soil Horizons we present a few snapshots of our current soil carbon research activities at Landcare Research. These include articles on assessing soil C stocks (p. 4–6), soil C storage mechanisms (p. 7), soil C measurement (p. 8), soil C change and the processes involved (p. 9–11), quantifying losses (p. 12–13), mitigation strategies to reverse soil carbon losses (p. 14), and modelling (p.15–16).

This issue of Soil Horizons pays tribute to Peter Stephens, creator of this newsletter, and a much respected science leader.

THE EDITORS



Peter Stephens 1946–2010

Peter Stephen's belief in 1997 that Landcare Research needed a newsletter to communicate our soils-related research to the wider community is as valid now as it was then. Peter therefore developed Soil Horizons and others have carried on his ideal. We would like to pay tribute to Peter, who died earlier this year. He was a much respected colleague and friend, and a number of Peter's close colleagues have contributed to these words.

Peter's passion was always for applied and practical research into land issues and remote sensing of land cover, erosion and land use. His early career saw him appointed as Area Soil Conservator for the Ministry of Works, Water and Soil Division, in Rotorua, where his work entailed land-use and land-capability mapping, particularly on land development blocks in the Central North Island. He went on to do postgraduate studies on aspects of erosion in the Southern Ruahine Range in 1975, before joining the Land Resources Group of Water and Soil Division in the Palmerston North Office to work on the NZ Land Resource Inventory.

Peter always had an eye for investigating new and innovative ways of doing things, and in 1977 he set up the Catchment Condition Group in an old cottage at the Aokautere Science Centre. This soon morphed into the Remote Sensing Group. Not only did Peter and his team pioneer the use of remote sensing techniques for mapping and evaluating land resources, they were one of the first government agencies to engage directly with the private sector.

To quantify the effectiveness of soil conservation practices, Peter was also instrumental in ensuring specially flown aerial photographs were applied. Working with Grassland Division and MAF, pasture measurement trials were set up on scars of different age and from these measurements it was shown that pasture production only recovered to about 80% of the productivity of the remnant forest soils – repeated landsliding on hillslopes was permanently reducing their productivity.

In March 1988, Cyclone Bola caused widespread flooding and landslides throughout the East Coast region of the North Island. Peter saw an opportunity to help with the disaster recovery effort that immediately swung into action, by providing region-wide SPOT satellite imagery. The damage assessment work was the first operational, land-based application of satellite image data at a regional scale in New Zealand, and used what was at the time a very novel (but today routine) approach:



the integrated use of the image data with existing map information to assess actual landslide scar area more accurately. Peter's enthusiasm for remote sensing, and its practical application, were always highly evident, and no more so than during the months following Cyclone Bola.

Peter served on the Council of the NZ Society of Soil Science and was President between 2002 and 2004. In 2003 he joined MfE in Wellington to design and project manage the Land Use and Carbon Analysis System (LUCAS), a project to measure and monitor the carbon stocks of New Zealand's forests and soils, which is a critical part of New Zealand's system for reporting under the Kyoto Protocol. He recently achieved recognition as a United Nations international reviewer for the Land Use and Land Use Change and Forestry sector of national greenhouse gas inventories.

Peter has left a void in the New Zealand science community that cannot be easily filled. He had wide knowledge and experience of New Zealand's landscape and environmental processes, and the ability to apply these to address complex issues. He was a people person who really cared about his colleagues and was always willing to share his knowledge – a very human scientist. To Lesley and Peter's family, and to his many friends throughout New Zealand, we extend our deepest sympathy.



Accounting for the effects of mass-movement erosion on soil carbon stocks

The Soil Carbon Monitoring System (CMS) estimates soil C stocks for each land use in New Zealand to determine the effect of changes in land use on soil C. It is based on a model that combines soil C data from New Zealand soils with national spatial datasets of soil type, climate, land use, and slope to derive estimates of soil C stocks. Early in the development of the CMS model it was recognised that it had several limitations, one of which was that it did not account for the effect of mass movement erosion on soil C stocks. The Ministry for the Environment recently engaged Landcare Research to define the most suitable approach to account for the effects of mass-movement erosion in the Soil CMS. Specifically we were asked to:

1. define the land subject to mass-movement erosion to be recognised in the Soil CMS
2. select a suitable approach to mapping that land and produce a map
3. compare and evaluate approaches that account for the effects of mass-movement erosion on soil C stocks, and their change with change in land use, in the Soil CMS
4. determine the most suitable approach, and develop an implementation plan.

Several approaches to defining the land subject to mass-movement erosion were explored, including actual and potential erosion recorded in the New Zealand Land Resource Inventory (LRI), erosion terrains, and the highly erodible land model. The definition of the land susceptible to mass-movement erosion affecting soil C stocks chosen was:

Shallow landslides affecting soil C stocks in hill country near Raglan.



“all that land recorded in the New Zealand Land Resource Inventory survey with the following erosion types recorded as potential erosion: soil slip (Ss), earth slip (Es), gully (G), debris avalanche (Da), slump (Su), earthflow (Ef)”.

In total 7 853 461 ha of land in North Island have potential for some form of mass movement (69% of North Island), and 8 991 907 ha of the South Island (60% of the South Island) (Figure 1).

Four possible approaches had previously been suggested to account for the effects of mass movement erosion on soil C stocks:

- Add land-use categories to encompass land subject to mass-movement erosion
- Sample eroded and uneroded land (on both grassland and forest land) to develop bias correction factors to apply to stock estimates
- Include a spatially continuous measure of mass-movement erosion risk as a factor in the Soil CMS model
- Sample areas subject to mass-movement erosion, stratified by land-use subcategory, to achieve proportional representation in the dataset.

Each of these approaches has advantages and disadvantages and the choice of the preferred approach involved compromise and prioritisation in quantifying the major effects of erosion on soil C. All the proposed approaches have difficulty dealing with the effects of temporal changes in erosion. The recommended approach was to develop a set of time-dependent bias correction factors (Figure 2) that account for mass-movement effects that could be applied spatially to terrains of differing mass-movement erosion susceptibility and different land uses, within the framework of the Soil CMS and the LUCAS Calculation and Reporting Application. The approach will use a series of case studies examining existing erosion data where possible, and measuring soil C to complement the erosion data. Then effects of key processes (landslides, earthflows, and gullies) on soil C stocks can be incorporated into the Soil CMS model.

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Legend

LRI Erosion Potential

Severity Class

- 1 - slight
- 2 - moderate
- 3 - severe
- 4 - very severe
- 5 - extreme

0 100 200 400 Kilometres



FIGURE 1 Potential mass movement erosion in New Zealand showing Land Resource Inventory (LRI) severity classes.

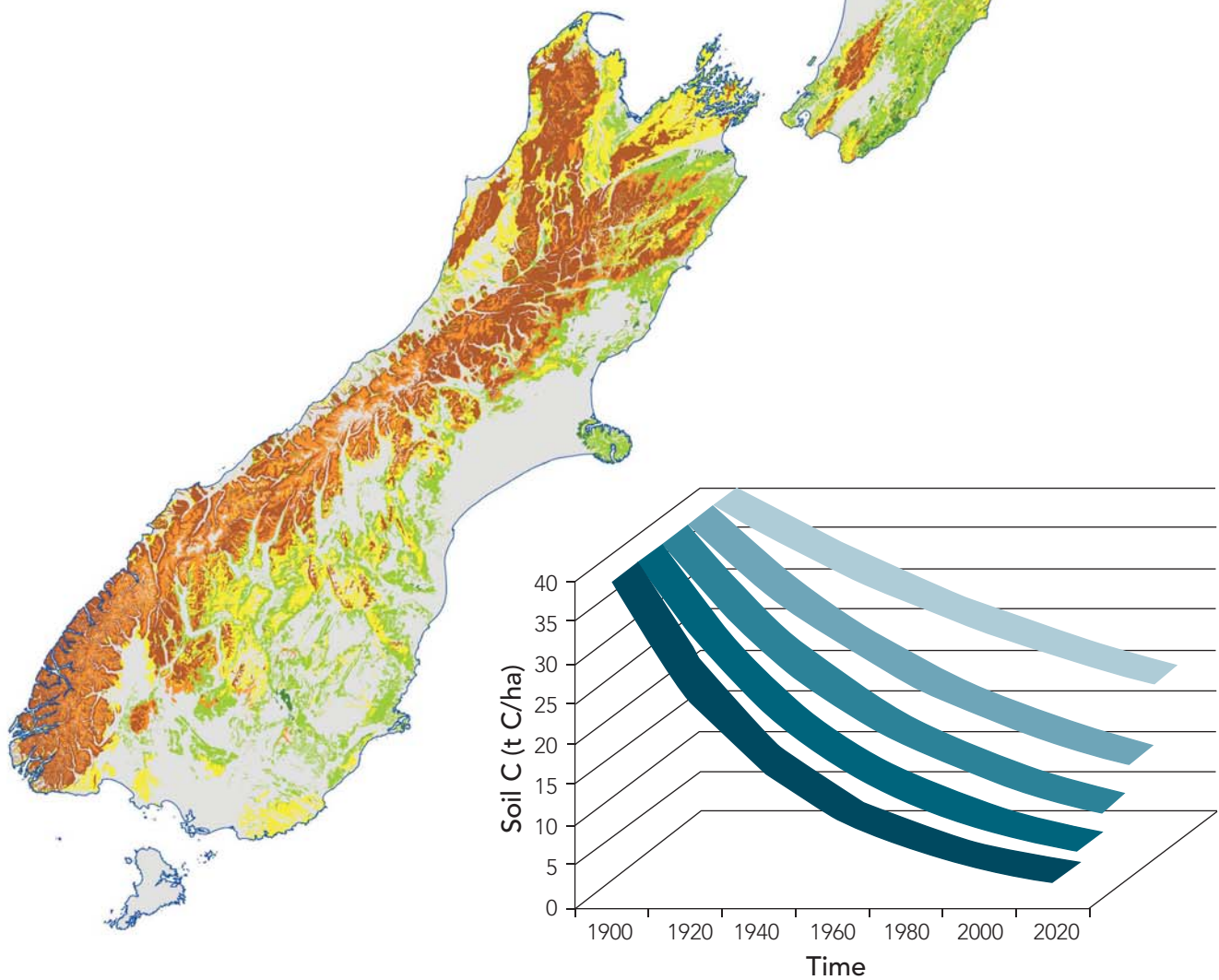


FIGURE 2 Theoretical landscape scale changes in soil C stocks between 1900 and 2020 on terrians of differing susceptibility to erosion, under constant land use.

A High Country C monitoring project

A MAF Sustainable Farming Fund (SFF) grant and other organisations have supported us to investigate the effects of grazing on ecosystem C stocks in South Island High Country grasslands. The project is exploratory and any changes are expected to be small, although due to the extent of land involved the potential to affect New Zealand and High Country C accounting is large.

The team set up a trial to test for the effects of land-use change on the ecosystem, selecting three locations with a known history of altered grazing management. In the headwaters of the Rakaia, Waitaki and Clutha (Table 1).

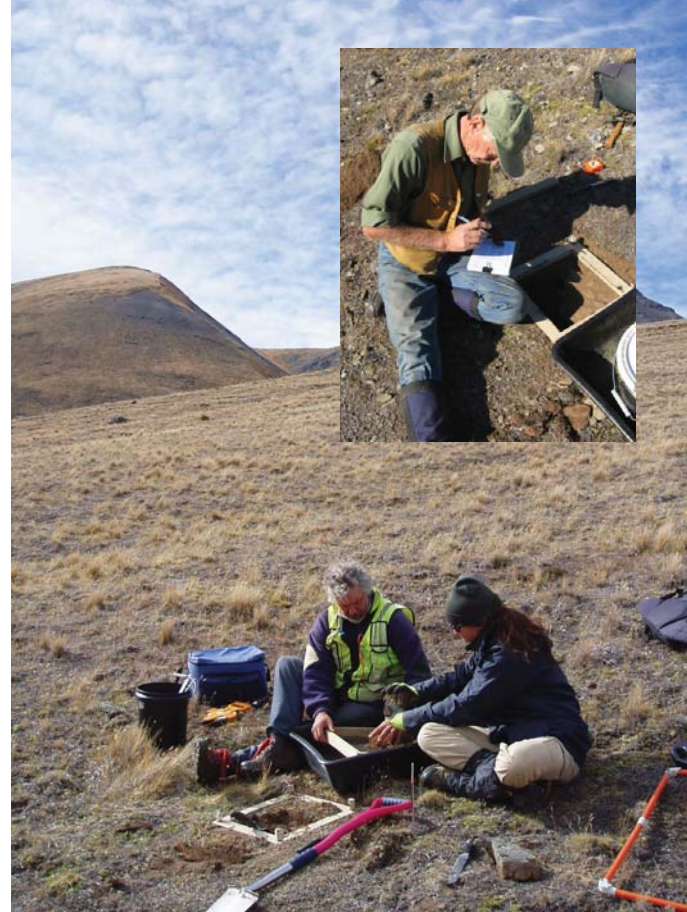
At each location comparable blocks of land were chosen: one block had been retired from sheep grazing and its paired block had continued with grazing as normal.

To ensure pairs of blocks were as similar as possible they were constrained within prescribed limits of elevation, slope, aspect and substrate. C stocks, elevation, aspect, slope, exposure, plant species, size and cover, sign of grazing and relative abundance were measured at about 20 random sample plots within each block. Quantitative samples from one square metre of above-ground vegetation biomass, litter, below-ground vegetation, and soil bulk density at 3 depths to 30 cm were collected.

Samples are currently being processed in the laboratory to quantify component C stocks and to determine if there is a difference in ecosystem C between land-use blocks.

The team anticipates the results will be influenced by:

- highly spatial variability of soil C even within the same soil type
- the presence of other grazing animals although sheep have been removed
- colder and drier sites where any observed C change may



Soil C monitoring in the South Island High Country.

be occurring more slowly

- invasive weeds such as *Hieracium* which alter vegetation ground cover
- fertiliser application, stocking rates, the time period since retirement, and the size of the labile soil C component.

It is uncertain if and how ecosystem C has changed as a result of any modification by Maori and early European pastoral practices.

Our results will contribute valuable data to work on tussock grasslands reported on page 10. In addition, our findings will be presented via the MAF (SFF) website during the coming year.

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RICHARD CLAYTON, IAN LYNN

TABLE 1 Key characteristics of locations selected for field sampling in April/May 2010.

Location	Elevation (m)	Rainfall (mm)	Topography	Predominant vegetation	Years since grazing change
Rakaia	1100–1400	1200–1400	Mountain slopes	Short tussock, <i>Hieracium</i> , <i>Celmisia</i> Spp.	42
Waitaki	800–1200	900–1000	Lateral moraine and mountain slopes	Snow tussock, short tussock, matagouri	28
Clutha	300–400	3000–4000	River terraces and fans	Exotic pasture grasses, lotus	12

C storage in Allophanic soils: possibilities and challenges

Reducing the emissions of greenhouse gases such as carbon dioxide into the atmosphere remains a huge challenge for the 21st century. Maintaining or increasing C storage in soil is of fundamental importance in dealing with this challenge.

Soil organic matter and its component C are stabilised in soil both with aluminium and through interactions with the smallest mineral particles, of which allophane, imogolite, ferrihydrite are the most reactive members. These reactive minerals, only nanometres in size, are abundant in New Zealand Allophanic Soils derived from pumice and volcanic ash. They have a strong propensity to adsorb humic substances, microbial biomass, and organic acids. Thus, Allophanic Soils usually have much higher C content than other soils in the same environment (see pages 10 and 11).

The ability of Allophanic Soils to stabilise organic matter may be utilised to maintain or even enhance soil C storage. To this end, facilitating the contact and mixing of organic matter (e.g., plant residue and root excreta) with the reactive minerals is important. This may be achieved by: (1) incorporating organic matter into subsoil layers where reactive mineral content is high; and (2) spreading the reactive mineral-rich subsoil on the surface of land. In either way, the reactive minerals can meet, capture, and stabilise the organic molecules from the decaying plant residue, root excreta, and microbial

biomass. The first method has not been extensively practised in New Zealand where pastoral agriculture predominates. However, it will occur under cultivation, although ploughing to a depth of about 20 cm would not mix organic residues with reactive minerals that are abundant at deeper depths (e.g., > 40 cm). In contrast, the second method has been occurring naturally since time immemorial. For instance, the Chinese Loess Plateau contains a 7-million-year record of aeolian deposits among which lie many ancient topsoil layers of high C content. Similarly, continuous volcanic-ash deposition surrounding Mount Aso in southern Japan together with the release of reactive aluminium from the ash have resulted in large C accumulation in topsoil (Fig. 1).

It was recently estimated that a change of 0.2% in soil C across the 11 million ha of grazed pasture in New Zealand represents a C trading value of \$5 billion. The significant economic implication of soil C change, the technological feasibility, and the agronomical and environmental effects of maintaining or increasing soil C content require investigation. These research topics are being addressed by the NZ Agricultural GHG Research Centre and SLMACC (Sustainable Land Management and Climate Change) projects initiated by MAF last year.

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FIGURE 1 C accumulation in a Japanese soil (black top layer is about 1 m, C = 16.8%) helped by volcanic ash deposition in the past 7000 years.



FIGURE 2 Allophanic soil near New Plymouth (C in the top 20 cm = 8.5%).



Proximal soil spectroscopy for soil C estimation and mapping

Soil samples in the New Zealand National Soil Archive are being scanned to collect visible-near infrared (Vis-NIR) soil spectra. The Archive contains approximately 25 000 soil samples, dating from 1939, and is housed near our Palmerston North site.

Soil Vis-NIR spectra provide a unique signature for each sample (Figure 1). We are developing chemometric methods to interpret accurately the spectra and extract information for soil moisture, C and N. A calibration set of spectra obtained from soils with known properties are needed to predict properties of unknown samples using their spectral signatures. The spectra can also be interpreted for a range of other soil properties, including clay content, mineralogy and soil function, for example denitrification potential and microbial C.

The aim of this spectral dataset is to provide a comprehensive spectral library for New Zealand soil spectra interpretation. We are also contributing our soil spectral library to a Global Soil Spectroscopy Group that intends to develop global calibrations for predicting soil properties. The Global library project aims to develop a global collaborative network for soil spectroscopy to

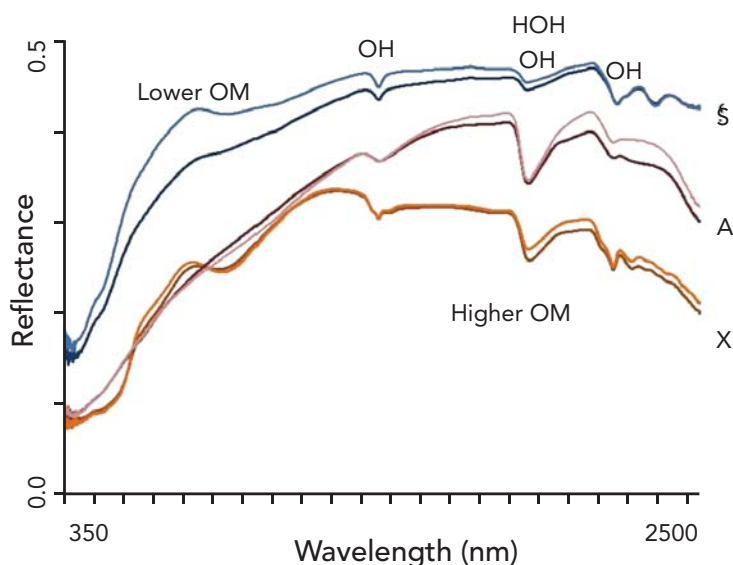


FIGURE 1 Soil spectra for Semi-arid (S), Allophanic (A) and Oxidic (X) Soils showing that soils with higher organic matter content exhibit less reflectance. The spectra also display the overriding effect of water (HOH) and hydroxyl bonds (OH).

further research and development and encourage its adoption in soil science.

Proximal Vis-NIR soil sensing is also being used to collect soil spectra from soil cores in the field at geo-referenced positions. Our research has found comparable accuracy for field-assessed soil C compared to that determined on spectra collected in the laboratory from air-dried, sieved samples. The denser sampling achievable by proximal sensing compared with conventional methods allows direct soil mapping and monitoring of soils using geostatistics.

Proximal soil spectroscopy with geostatistical interpretation of geo-referenced datasets will be used to improve our soil C mapping methods at the paddock scale, where spatial variability of soil C measurements has been found to vary largely over a distance of just a few metres (e.g. Figure 2). Spectral sampling position is targeted to sample the complete range of variability within the landscape, and the sampling strategy is determined from soil electrical conductivity and digital elevation maps obtained using on-the-go electromagnetic induction soil survey equipment.

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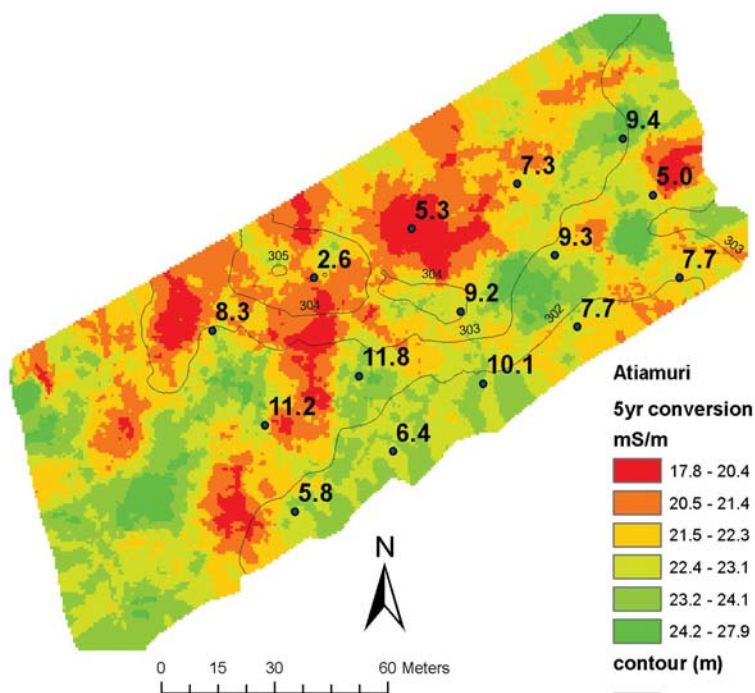


FIGURE 2 Soil electrical conductivity map showing soil C content [numbers on map] varying between 2.6% and 11.8% in a paddock where pine forest has recently been converted to pasture.

Soil form, carbon storage and stabilisation

Soil C can change under different land uses (page 11). For example, soil C has been shown to decline with intensification of dairy farming on flat land, and with irrigation in Canterbury.

Soil is a physical, chemical and biological self-organising system where chemical and biological interactions on physical surfaces, such as clays, occur within soil pores. As a consequence, the physical structure and architecture of soil can not only be influenced by the chemical and biological activity in soil, but can also play a significant role in affecting chemical and biological activity.

Various models have been developed to predict soil C dynamics. Most, however, do not take account of the soil structure and architecture. We are learning how soil structure and architecture may influence soil C and N storage and stabilisation and if the research can be used to improve modelling of C dynamics.

X-ray computed tomography

With soil X-ray computed tomography (CT) we can quantify in 3D a soil's architecture (Issue 17, p. 2). Figure 1 shows an example of a 3D CT image under two orchard systems on the same soil with different soil pore networks. Quantifying the pore size distribution, topology and the pore surface density can help us understand the biogeochemical interactions that affect the gains and losses of soil C. We are currently analysing micro-CT data generated using a synchrotron to quantify microbial habitat within soil aggregates under low and high fertility pasture.

Aggregation

We have recently shown that land use affects soil aggregation and C dynamics within organic matter pools associated with soil aggregates (Issue 18, pages 10–11).

With the intensification of some of our hill country sheep farms, application of N can increase production. In collaboration with AgResearch and the University of Waikato

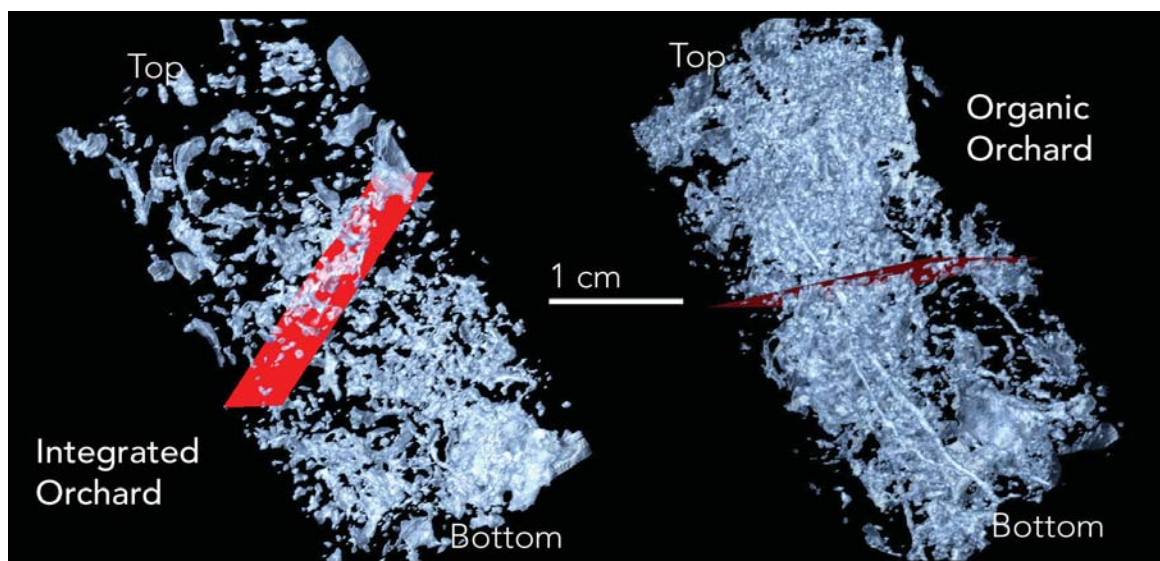


FIGURE 1 Examples of macropore networks in the top 50 mm of soil under trees in two apple orchards in Hawke's Bay determined using X-ray computed tomography. The grey coloured areas are macropores. Left: Macropore network of the **integrated** orchard system. Macroporosity is 2.9% (volume) and mean macropore radius 0.38 mm. Right: Macropore network of the **organic** orchard system. Macroporosity is 8.3% (volume) and mean macropore radius 0.41 mm.

we found soil particulate organic matter (both outside and inside microaggregates), and microaggregate-associated silt and clay C, increased with increased N and stocking rate within the first 3 years.

Previous studies have shown that increased N inputs may cause a decline in soil C; however, we found no decline. There was no relationship between the natural abundance of the isotopes $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ in any soil fraction and the amount of N leached, suggesting organic matter decomposition was not a contributing factor to leached N. Rather, there was an increase in the particulate organic matter inside microaggregates (the physically protected particulate organic matter) with increasing N fertiliser rate. Not surprisingly, a slight change in the isotope abundance within the particulate organic matter outside microaggregates indicated this fraction was the most susceptible fraction to start decomposing at this early stage of increasing soil N nutrition.

By measuring the soil architecture and soil C fractions we are able to understand "how the soil works", which may make it possible to develop models for improved management strategies.

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Changes in soil organic matter under pasture over the last 27 years

Roger Parfitt and colleagues from Landcare Research, GNS and University of Waikato have measured soil C under the same dairy and sheep/beef pasture sites on three occasions over the last 27 years. They previously reported on the changes between approximately 1982 and 2004 for 30 sites where they found soil C was decreasing by 0.8 tonnes C/ha/year for the whole soil profile. International reporting (IPCC) requires reporting for a soil depth of 0–30 cm. Data have now been obtained for 83 sites, and sheep and beef farms, and tussock soils, show no measurable loss of soil C between 1982 and 2004 (Figure 1). However, there was a significant loss of 0.7 t C/ha/year for 29 dairy sites. The average losses were similar for Non-Allophanic soils and Allophanic soils, although the Non-Allophanic soils contain less total C (122 t/ha to 105 t/ha) compared with Allophanic soils (194 t/ha to 176 t/ha) (Figure 1).

Preliminary soil C data for 2009 from 22 farms (Figure 2) indicate no further measurable loss of C between 2004 and 2009, but it may be that insufficient time has passed to be able to detect ongoing change in soil C stocks due to within site variability. As mentioned on page 8 there is considerable variability of soil C within a paddock, and we are investigating how many sites need to be measured, over how many years, in order to get a robust measure of change in soil C.

The possible reasons for the loss of soil C under dairy are also being investigated. The use of N fertiliser increased from 1990 to 2004 (Figure 3) mainly on dairy farms, and over this time pasture has been farmed more intensively. For dairy pastures, the soil C:N ratio appeared to decrease from 11.4 to 11.1, suggesting soil N fertility was increasing. With increased N input there may be less C input from roots to soil, and there will be greater additions of cow urine-N to the soil. Preliminary work suggests cow urine can accelerate decomposition of soil organic matter (Issue 18, p. 9). The intensive use of pasture under dairying may therefore contribute to the loss of C. Since 2004 the use of N fertiliser has not increased but it is probably too early to say whether soil C has arrived at a new level.

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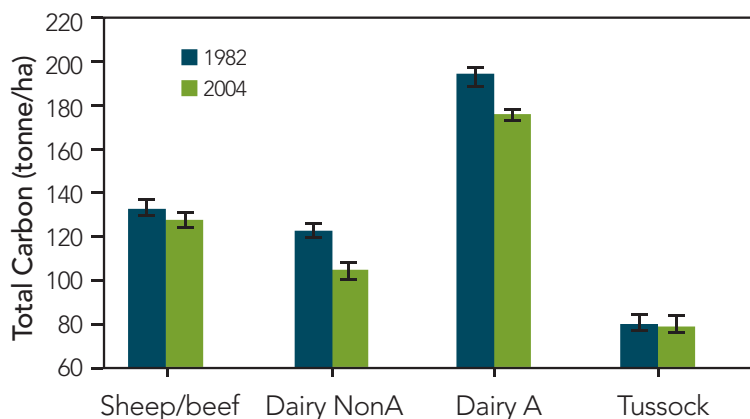


FIGURE 1 Soil C for 0–30 cm depth at sheep/beef farms, dairy farms on Non-Allophanic Soils (NonA) and dairy farms on Allophanic soils in Taranaki and Waikato (A), and Tussock. Error bars are standard error of the mean.

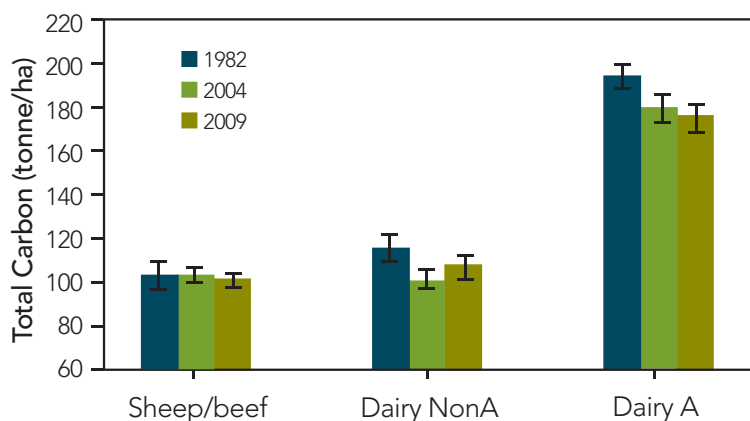


FIGURE 2 Soil carbon at sheep/beef farms, and dairy farms on Non-Allophanic Soils (NonA) and dairy farms on Allophanic soils in Taranaki and Waikato (A), for 0–30 cm depth for 22 sites. Error bars are standard error of the mean.

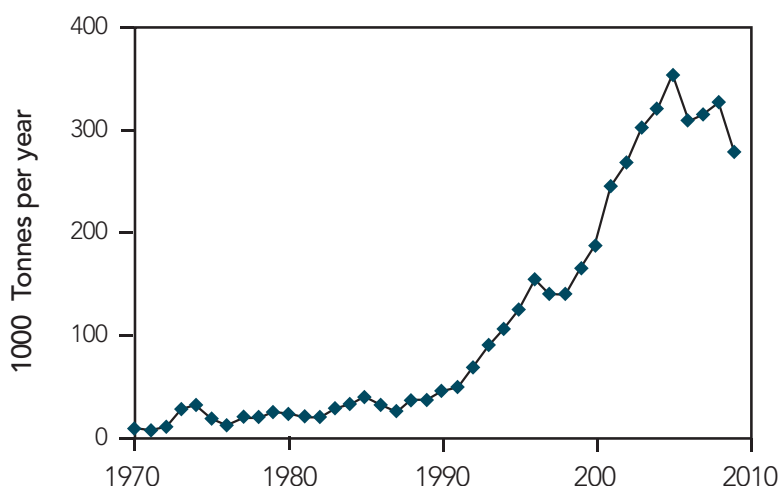


FIGURE 3 N Fertiliser consumed in NZ (H. Furness, pers. comm.).

Land use and soil type affect soil C – lessons from 15 years of soil quality monitoring

The ETS (Emissions Trading Scheme) is now a reality, and C accounting is more important than ever. Accounting for all the soil C and how it changes over time is not an easy task. The soil quality programme developed by Landcare Research in concert with Regional Councils has information on 750 sites, and some have been monitored two or three times over the last 15 years. Seven soil quality indicators relating to soil physical, chemical and biological status – total C being one of these – have been measured. Although only the top 10 cm was sampled, these data provide valuable information on how C differs with land use and soil type.

Dairy pastoral soils have the largest average C stocks followed by indigenous forest (Figure 1), although page 10 explains that soil C can be lost under dairying with time. Dairy pastoral soils also have large N stocks (note the difference in N between dairy and indigenous forest). Cropping soils have the least amount of C in the topsoil as cultivation breaks up the aggregate structure that helps protect organic C, and erosion on bare fields can wash soil C away.

Soil type also matters, as the texture, mineralogy and chemistry of a soil partly determine how quickly soil C can change and recover. Allophanic Soils generally have the highest soil C and Recent Soils the least (Figure 2) (see page 7).

C accounting on a national basis is difficult because land use and soil type affect soil C. Spatial modelling extrapolates sampled points in particular soil/land-use combinations to similar soils, but even so, complete and accurate measurement of soil C levels across New Zealand requires considerable effort. New quicker methods of analysing soil C content in the field will help the process (page 8).

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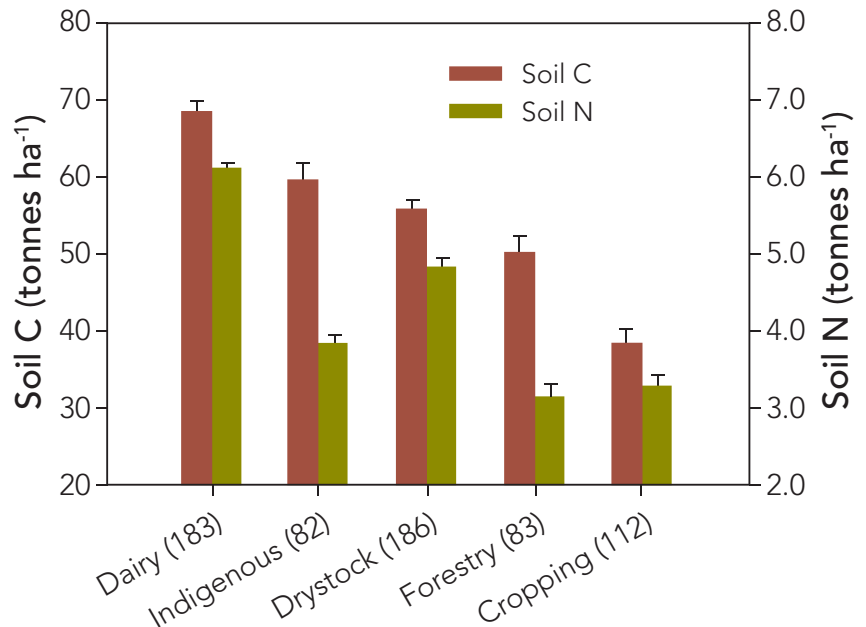


FIGURE 1 Average soil total C and total N concentrations to 10 cm depth for major land uses (number of sites sampled in parentheses). Error bars represent one standard error of the mean. Note the difference in scale for C and N (updated from Sparling and Schipper (2004)).

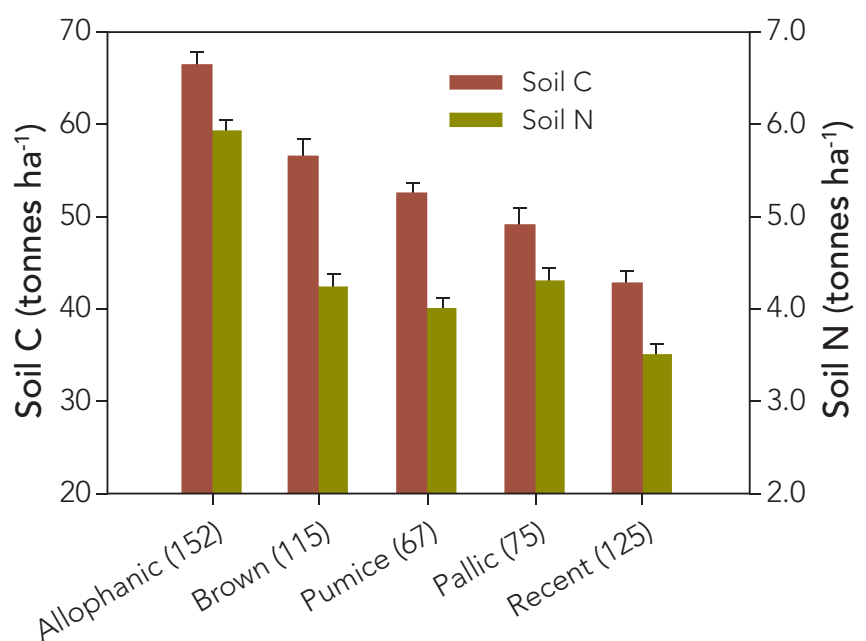


FIGURE 2 Average soil total C and total N concentrations to 10 cm depth for some soil orders (number of sites sampled in parentheses). Error bars represent one standard error of the mean. Note the difference in scale for C and N.



Soil erosion in New Zealand is sinking carbon (C) at 3 million tonnes per year

Over two hundred million tonnes of sediment are lost from New Zealand to the ocean every year, primarily during storms. Intense rainfall erodes soil from steep slopes and this ends up in waterways as sediment. Floodwaters carry the sediment to the ocean and deposit it on the ocean floor. As the sediment contains about 2.4% organic C, this means a total of 4.8 million tonnes of C is exported to the ocean from New Zealand each year. This is a lot of C to lose – equivalent to 70% of New Zealand’s total use of C through the burning of fossil fuels in 1990.

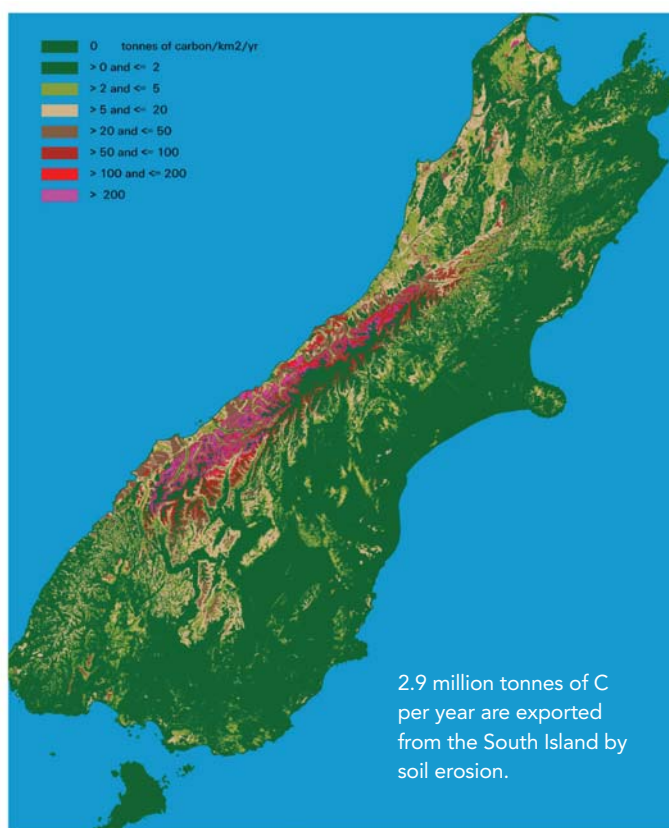
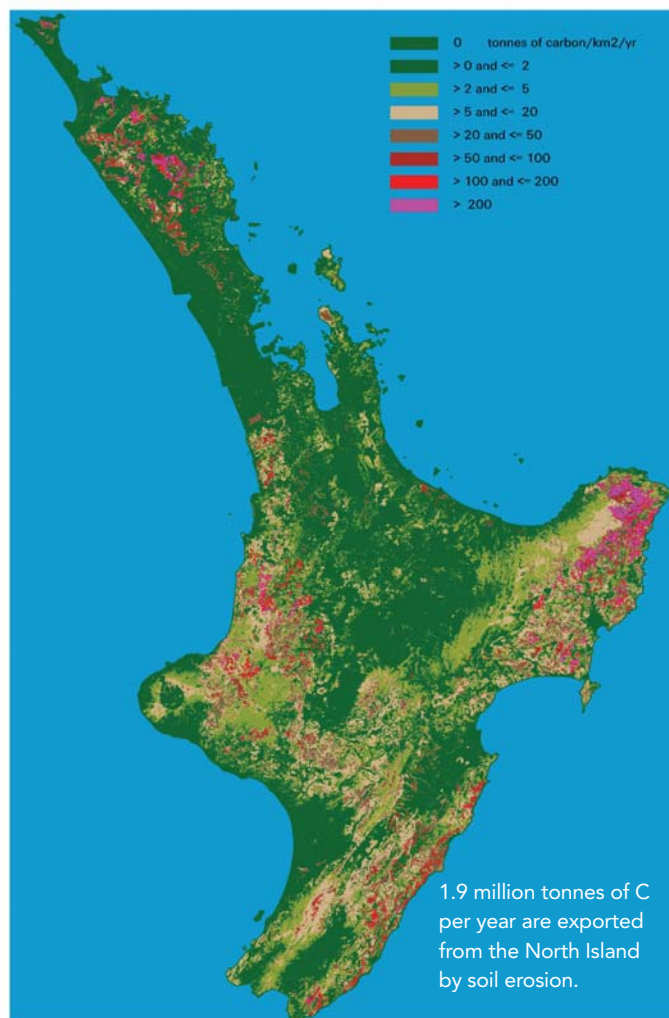
This loss of C initially appears like a bad news story. But John Dymond of Landcare Research has discovered otherwise. He estimates that soils recovering from erosion are sequestering C on average at nearly the same rate that C is lost through erosion. Assuming most (~80%) of the sediment is buried permanently on the ocean floor, erosion is responsible for a net sink from the atmosphere of 3.1 million tonnes of C.

CO₂ from the atmosphere is sequestered to soil organic C in soils recovering from erosion, and then transported after a new cycle of erosion to the ocean, where it is buried.

New Zealand chose not to opt for full carbon accounting in its Kyoto Protocol negotiations, so the significant C sink in soil is excluded from eligibility for carbon credits. Further, most of the erosion in the North Island was caused by the clearing of native forests over 100 years ago, so it is well outside the 1990 baseline set in the Protocol. However, if New Zealand ever decides to negotiate a full C accounting method, then soil erosion could possibly qualify as a major C sink (see pages 4–5).

Dr Dymond strongly cautions against thinking soil erosion could be considered a good thing and we could do with some more of it. Soil erosion impacts on water quality and reduces productivity. A certain base level of natural erosion is beneficial through a greenhouse gas perspective, only when the soils can sequester C as fast as they lose it through erosion. Excessive erosion however, is dangerous and can lead to complete collapse of some landscapes, where there is no soil recovery (such as the gullied landscapes in the soft-rock hill country in the Gisborne district). If these landscapes were reforested to reduce erosion then the net C sink for New Zealand would be even greater.

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Quantifying the loss of soil C from soil organic matter, as a consequence of climate or land-use change

Soils are the largest pool of C in terrestrial ecosystems, and some of the C in soil organic matter (SOM) is resistant to decomposition, taking from decades to millennia to decompose (hence its description as 'historical' C). Yet it is the carbon dioxide (CO₂) from 'historical' C that, with photosynthesis, determines an ecosystem's source-sink balance of C in and C out. To measure this flux, it must be distinguished from the CO₂ arising from the respiration of living roots, fungal hyphae and microbes, as all contribute to the soil flux. Conventional methods involve killing roots and hyphae, removing litter from the soil surface, or introducing SOM whose C is distinct from that of native soil C. All these invasive procedures can, worryingly, produce estimates of CO₂ fluxes that do not necessarily reflect those of undisturbed systems. Knowing how the 'historical' CO₂ flux varies between different ecosystems and in relation to temperature and moisture would be a major step towards improving climate models, most of which use information about these CO₂ fluxes.

Our solution to this long-standing problem has been to develop a method that measures 'historical' CO₂ fluxes directly, but with minimal disturbance. We do this by accurately measuring the natural isotopic (¹³C) composition of CO₂ derived from the decomposition of SOM and from the respiration of living roots. These sources of CO₂ usually differ in their ¹³C content by a small, but measurable, amount. By measuring the CO₂



FIGURE 1 Equipment used to collect the soil surface CO₂ efflux in order to measure its isotopic composition.

flux at the soil surface and its ¹³C content (Figure 1), we can estimate directly how much of it derives from 'historical' C. We have tested this approach at a range of field sites and found we can measure the loss of this 'historical' C without any disturbance of the system. We are now assessing the impact of soil temperature on SOM turnover in order to improve the description of temperature sensitivity of SOM decomposition in existing models that predict interactions between climate and the C cycle and that forecast resulting changes in the C stocks of ecosystems.

One finding from this work is that when soil is disturbed, the ¹³C signature of the CO₂ arising from respiration rapidly changes (Figure 2). Systematic loss of soil C following soil disturbance is attributed to loss of physically protected SOM. Such protection occurs due to a range of factors, including reduced oxygen diffusion into soil aggregates and physical separation from soil microbes. Any soil disturbance through land-use change or cultivation that leads to a break up of soil aggregates releases labile C, which is then accessible to decomposition. Our new isotope approach offers the possibility of quantifying labile soil C pools that are vulnerable to loss through disturbance. This research is being conducted collaboratively with Andy Midwood of the Macaulay Institute, Aberdeen, Scotland.

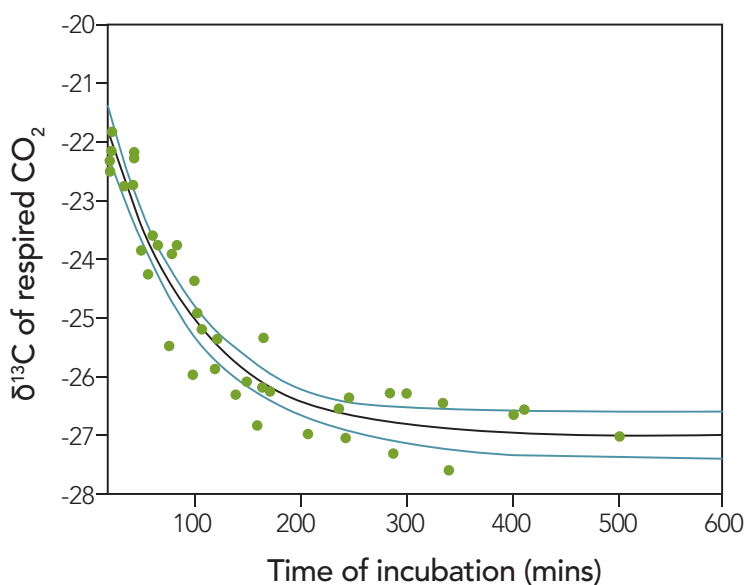


FIGURE 2 The effect of length of incubation on the ¹³C isotopic signature of CO₂ from soil respiration, following a disturbance to the soil. The change in signature is due to the start of a rapid turnover of labile soil C. The blue lines show 95% confidence intervals.

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Soaking up the veterinary antibiotics through black C

'Black carbon' (i.e. char, charcoal, and soot) is a high C-rich material and has a significant influence on the mobility and retention of chemicals in soils. Laboratory, field studies, and traditional farming practices suggest deliberately added black carbon (as charcoal, "biochar") can impact on soil fertility, crop production, and availability of nutrients. Fundamental knowledge of how black carbon reacts with various compounds and with soil biological constituents is important to engineer black carbons that will best meet specific environmental applications, such as remediation of contaminated land.

Each year, New Zealand farmers use around 60 tonnes of veterinary antibiotics to prevent and treat diseases and to a lesser extent promote growth. But 80% of each dose passes straight through the animal and ends up in the environment. Soil- and water-dwelling microorganisms exposed to these antibiotics develop resistance, which in turn can be transferred back to both livestock and humans. Therefore researchers at Landcare Research have come up with a novel way to soak up these unwanted contaminants – and increase soil fertility at the same time. The solution may lie in biochar – obtained by burning biomass in the absence of air. Biochars can be made easily from green waste, sawdust, and even corncobs. Since biochar can contain 80% C and is

resistant to decomposition, it is a form of C sequestration, thus also contributing to reducing greenhouse gases. Landcare Research scientist Dr Ajit Sarmah and PhD student Prakash Srinivasan tested the absorption properties of three different biochars, and their preliminary findings suggest biochar made from pine sawdust produced using the steam gasification process, is the most effective in sorbing contaminants.

Biochar made from pine sawdust absorbs 150 times more contaminants than soil alone because it has a very high surface area, high C content (~ 90%), and is more porous than other biochars. Its surface area is four times bigger than that of corncob and green waste biochars. It is envisaged that biochar applied at the rate of 10 tonnes per hectare could prove effective in slowing the release of contaminants. Biochar produced from pine sawdust was also found to be the most effective uptaker of antibiotics and hormones when amended with soil. Further work will be required to test these results under realistic field situations.

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FIGURE 1 Pine sawdust biochar.



FIGURE 2 Corncorb biochar.

Effects of monthly versus annual mean temperature data for modelling soil organic matter decomposition

Global models generally agree that warming will lead to a loss of soil organic C, while increasing CO₂ is expected to stimulate plant net primary productivity and increase C stocks. However, predictions of the combined effect of increased CO₂ and climate change vary greatly between models.

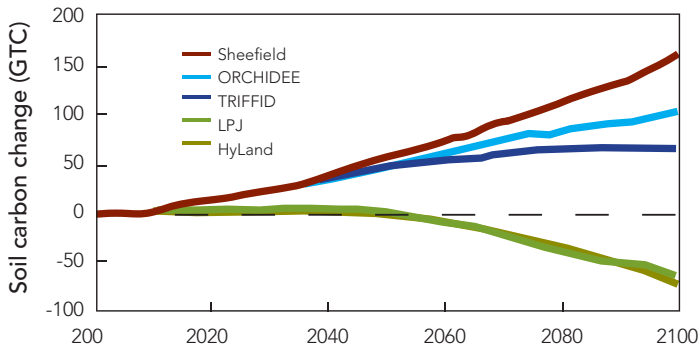


FIGURE 1 Five dynamic global vegetation models (as specified in the Figure) run under the SRES A1F1 climate change scenario, which includes changes in CO₂ concentration as well as climatic drivers.

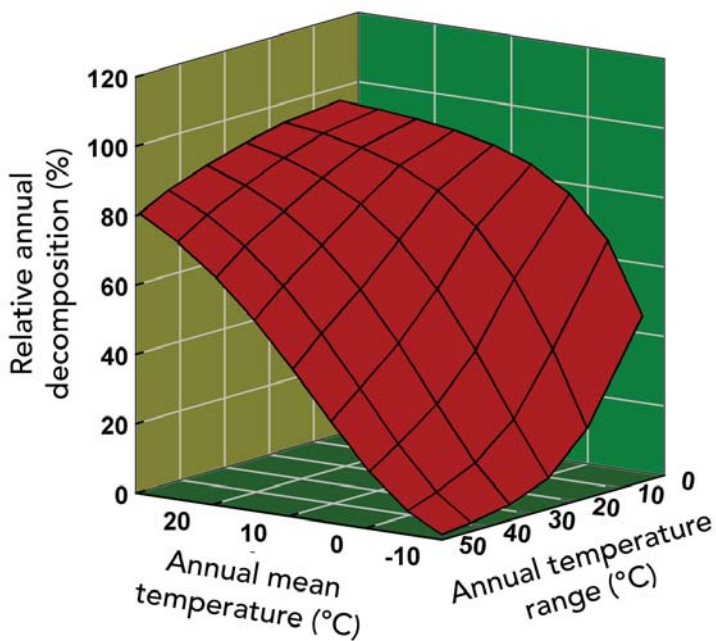
This is aptly illustrated in a study by Sitch et al. (2008) who ran five global models to the end of the 21st century with

the same projected climatic changes as key input (Fig. 1). The models disagreed considerably on the magnitude and even the direction of net changes in soil C. The magnitude of the disagreement amounted to over 200 GtC (billion tons of C) between the most extreme simulations. That extent of uncertainty is greater than all the C released globally from all land-use changes to date.

This large disagreement is most disconcerting as it has a direct bearing on the urgency with which climate change mitigation has to be addressed. If the more benign simulations are correct then we have more time and flexibility in responding to climate change, whereas the more pessimistic simulations would call for much more urgent and drastic mitigation responses.

A detailed analysis of the simulations revealed that much of the differences between simulations critically depended on the temperature sensitivity of organic matter decomposition. Much of our understanding of such sensitivities is based on short-term studies that generally show a strong temperature sensitivity of organic matter decomposition. However, many climate change models use longer (annual) time steps. Dr Miko Kirschbaum has investigated the extent to which short-term temperature

Based on annual air temperature



Based on monthly air temperature

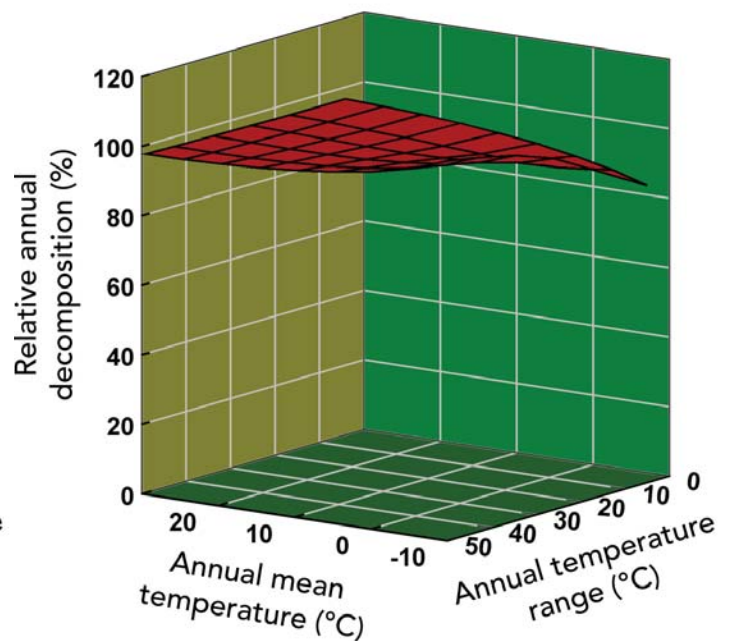


FIGURE 2 The effect of using annual mean air temperature or monthly mean air temperature to estimate annual decomposition activity for systems with different annual mean temperatures and temperature ranges. All data are expressed as a percentage of the decomposition activity calculated from daily soil temperatures.



FIGURE 3 The comparatively low seasonal temperature range of maritime climates is one factor that causes relatively low annual soil organic matter decomposition rates, compared to regions experiencing higher seasonal temperature range.

response functions can be used for long-term global applications, by determining how predictions of changes in soil C stocks are affected by the inclusion or omission of inter-annual temperature variations.

Results indicate that for global applications, it is critical to consider seasonal temperature variations. Short-term measures of temperature dependence cannot be applied at different temporal scales without explicitly considering the variability of temperature over the longer temporal scale. Using short time steps of at least months in simulations results in greater annual decomposition activity, especially

for cold regions, than would be predicted by simulations that use only annual time steps (Fig. 2).

So what does it all mean? The nature of feedbacks from soil carbon storage strongly affects the extent of ultimate climate change caused by a given amount of fossil-fuel emissions. Inclusion of the seasonal temperature cycle somewhat reduces the concerns that global warming could lead to significant additional losses of soil carbon stocks, especially in cold regions. It is thus one bit of good news that somewhat allays concerns that human fossil-fuel emissions could be compounded by natural feedback processes.

More generally, the work showed that the temperature dependence of organic matter decomposition cannot be quantified without specifying the spatial and temporal scale over which it is used. There is a wealth of observations at small and short scales. Long-term and global responses can be derived from these short-scale observations, but only with further analyses to understand and incorporate the factors that operate and interact at these various scales of interest.

New Zealand's generally more maritime climate, and consequent low seasonal temperature range, is one factor that causes low annual decomposition rates (Fig. 3). This, in turn, leads to higher soil C stocks than for regions with similar mean temperature but higher seasonal temperature range.

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